AD-785 520

AN IMPROVED PROJECTILE BOATTAIL

Anders S. Platou

Ballistic Research Laboratories

Prepared for:

Army Materiel Command

July 1974

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER BRL Memorandum Report No. 2395	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER AD-785520	
4. TITLE (and Subtitle) AN IMPROVED PROJECTILE BOATTAIL	5. TYPE OF REPORT & PERIOD COVERED Final
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Anders S. Platou	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Ballistic Research Laboratories Aberdeen Proving Ground, Maryland 21005	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS RDT&E 1T161102A33D
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Materiel Command 5001 Eisenhower Avenue Alexandria, Virginia 22304	12. REPORT DATE July 1974
	13. NUMBER OF PAGES 41
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	15. SECURITY CLASS. (of this report) UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Details of illustrations in this document may be better studied on microfiche

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Projectiles
Aerobalistics
Magnus
Bodies of Revolution
Gyroscopic Stability

20. ABSTRACT (Continue on reverse side if necessary and identify by block number) (ds/lca)

A series of projectile boattails have shown improved aerodynamic performance over the standard conical boattail. These boattails have equal or lower drag and an improved gyroscopic stability. Their Magnus and damping characteristics appear to be satisfactory so that the projectile should be dynamically stable. Also, these boattails increase the projectile wheel base considerably, thereby decreasing the balloting in the gun tube. The improved aerodynamic performance could lead to longer ranges, longer projectiles or lower spin rates for future projectiles.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

TABLE OF CONTENTS

Preceding page blank

LIST OF ILLUSTRATIONS

Preceding page blank

LIST OF ILLUSTRATIONS (continued)

I. INTRODUCTION

The purpose of a projectile boattail is to reduce drag, thereby increasing the range of the projectile. The standard conical boattails reduce the drag, compared to the cylindrical tail* (Figure 1); however the conical boattail creates a "negative lift" which reduces the projectile gyroscopic stability. The conical boattail also generates large Magnus moments at transonic speeds which can decrease the dynamic stability of the projectile. Gyroscopic and dynamic stability must be maintained in order that the average angle of attack decreases as the projectile moves along its trajectory.

Recently it has been found that drag reductions can be attained without creating the "negative lift" and reducing the gyroscopic stability by using a new type of boattail. These boattails are formed by cutting the main projectile cylinder with planes inclined to the main cylinder axis by a shallow angle, such that fin like surfaces are created on the boattail. These boattails all have elements of the main projectile cylinder extending to the base and also have a much better crossectional area-reduction gradient than the conical boattails. It is believed that these physical properties of the new boattails reduce the viscous region in the vicinity of the boattail and improve its aerodynamic performance. Possible versions of these boattails are:

(1) A boattail formed using four cutting planes so that the base becomes an inscribed square (Figure 2).

(2) A boattail formed using three cutting planes so that the base becomes an inscribed triangle (Figure 2).

(3) Boattails formed similar to (1) or (2) but with the cutting plane widths limited so that added lifting surfaces are formed at the base corners (Figure 3).

(4) Boattails formed similar to (1), (2), and (3) but with cutting planes canted at the gun twist angle (Figure 4).

(5) A boattail formed by eliminating all of the main body cylinder volume not included inside the volume of two orthogonal wedges (Figure 5). This version can be extended to zero base area or can be cut off at any station to form a cruciform base (Figure 6). The boattail length providing minimum drag will depend on the location of flow separation and can only be determined experimentally.

**Previously known as a square base configuration but changed here to avoid confusion with the new version (1) boattail.*

Patents applied for 2 June 1972 and 8 October 1973 for the boattail shapes mentioned in this report.

All of these new boattails were originally conceived to minimize the increase in Magnus forces and moments at transonic speeds occurring on the conical boattails. It was believed that the cylinder elements extending to the base will form crude fins which would have Magnus forces acting opposite to those on the body[1]. Thus, the opposing forces would minimize the resultant Magnus force and possibly the Magnus moment. Aerodynamic tests on these configurations were deemed advisable in order to verify these beliefs and also to choose the configuration giving the best overall aerodynamic performance.

Aerodynamic tests on these boattails are being run over the trisonic Mach number range, M = .5 to 4.0, to evaluate the aerodynamic forces and moments acting on the projectile. Range and wind tunnel tests are being used to complement each other so that good, reliable aerodynamic information will be available.

Also a triangular nose formed similar to the triangular boattail, but continued to a point, will be tried. The nose will be canted at the gun twist angle to prevent loss of spin and may provide a low drag with very good wheel bearing.

II. TEST FACILITIES

The wind tunnel facilities used for the tests so far are:

(1) The NASA Ames Research Center 12 ft. subsonic wind tunnel, M = .5, .7 and .9, 4-1/4" model, Re/ft = 1.35 to 2.8 x 10^6, (Re/m = 4.23 to 9.2 x 10^6).

(2) The Naval Ship Research and Development Center (NSRDC) 7 ft. x 10 ft. transonic wind tunnel, M = .5, .7, .9, .94 and .98, 4-1/4" model, Re/ft = 2.65 to 4.0 x 10^6 (Re/m = 8.69 to 13.1 x 10^6).

(3) The Ballistic Research Laboratories (BRL) 1 ft. supersonic wind tunnel, M = 1.75 to 4.0, 2-1/4" model, Re/ft = 3.6 to 7.0 x 10^6 (Re/m = 11.8 to 23.0 x 10^6).

III. WIND TUNNEL MODELS

These boattails are being tested using the Army-Navy Spinner Rocket nose and body with the complete configuration being both 5 and 7 calibers long. Later tests of some of the boattails may be run using a lower drag nose.

---

1. *A. S. Platou, "Magnus Characteristics of Finned and Nonfinned Projectiles," AIAA Journal, Vol. 3, No. 1, January 1965, pp. 83-90.*

Two sizes of models, 2-1/4" (5.715 cm) and 4-1/4" (10.795 cm) diameters, are required for the wind tunnel tests because of the variation of the tunnel sizes available for the different speed ranges. The models are designed according to the specifications described in reference 2. They consist of a central body mounted on ball bearings and a strain gage balance with various tails and noses attached to the central body. Variations in the lengths of the noses and tails make it possible to test body lengths of 5, 6 or 7 calibers. The strain gage balances used are numbers SB228B or C, SB4-1C and SB4-5C.

Tails for each boattail version, listed previously, are made using a 7° cutting plane angle for both the 2-1/4" and 4-1/4" diameter models. Also, a straight cylindrical tail and a 1 caliber long 7° conical boattail are available for reference data (Figure 1). Each boattail version can be tested on the 2-1/4" diameter body with configuration lengths of 5, 6 or 7 calibers; however, the 5 caliber, 4-1/4" model is limited to the straight cylinder, the conical boattail and the square boattail. Six and seven caliber, 4-1/4" diameter models of all the boattail versions can be tested.

IV. RANGE MODELS

A few configurations have been fired in the BRL aerodynamics range at transonic and low supersonic speeds and additional firings are planned for the near future at all Mach numbers from .8 to 4.0. The models are 20mm diameter and made mainly from aluminum with longitudinal base holes for adjusting the center of gravity. The models are launched using keyed pusher plates so that regular projectile rotating bands are not required. The barrel rifling used for these tests have twists of 1 revolution in 15 calibers or 1 revolution in 19 calibers.

V. RESULTS

So far very little data have been obtained on the 7 caliber configurations since tunnel and range time have not been available. Therefore, only the 5 caliber data are presented here; however, the available 7 caliber data do support the 5 caliber results.

The first tests at NASA Ames Research Center indicate that the measured drag of these boattails is comparable to the drag of the 1 caliber conical boattail. However, base pressure measuring difficulties

---

2. *A. S. Platou, R. Colburn, and J. S. Pedgonay, "The Design and Dynamic Balancing of Spinning Models and a Testing Technique for Obtaining Magnus Data in Wind Tunnels," Ballistic Research Laboratories Memorandum Report No. 2019, October 1969, AD 699803.*

make it impossible to obtain estimated free flight drag values so these data are not presented here. Free flight data, obtained in the BRL aerodynamics range at a later date, do show that the drag values are comparable at transonic speeds (Figure 7) to the conical boattail. Additional free flight drag data on these boattails are required in order to determine their performance over the complete speed range. Drag data at supersonic speeds, from BRL Wind Tunnel No. 1, also indicates the triangular and cruciform wedge boattails have lower drag values than the 1 caliber conical boattail (Figures 8 and 9). No data are yet available on the cruciform wedge boattail at subsonic and transonic speeds.

The subsonic tests at Ames also indicate a more rearward center of pressure of the normal force and lower pitching moments than the conical boattail (Figures 10, 11 and 12). The transonic tests at NSRDC and the BRL range confirm these results at higher Reynolds numbers and the tests in BRL Wind Tunnel No. 1 show the increased stability is also present at supersonic speeds. At supersonic speeds the new boattails have higher normal forces and better stability characteristics than the cylindrical tail (Figures 10, 11 and 12). The range firings also show better stability through the transonic speed range.

The increased normal force or lift developed on these new boattails is contrary to the slender body theory for bodies of revolution and at this point is not clearly understood. It is possible that the increased lift is entirely due to the lifting surfaces on these boattails; however, it is also possible that the more gradual reduction of crossectional area (Figure 13) may reduce the viscous region and maintain a more uniform Bernoulli head in the vicinity of the boattail. To gain insight into this problem it is planned in the near future to obtain the lift and pitching moment on two additional configurations: (1) a boattail with circular crossections and having the same area distribution as the cruciform wedge and (2) a conical boattail having four in-caliber fins. It is expected that the first boattail will have more lift than the conical boattail, but less than the cylindrical tail while the finned conical boattail will have more lift than the cylindrical tail, but less than the cruciform wedge.

The tests at Ames and NSRDC have almost eliminated the added lifting surface versions (Figure 3) since the drag increment due to the larger base area is too high, while the added lift and stability are minimal. Tests, when time permits, may show that these lifting surfaces may perform better at supersonic speeds.

The Magnus data on the new boattails are not yet as well determined as the pitch data, because of the more difficult testing techniques. In general, the Magnus characteristics are nonlinear in spin, angle of attack, Reynolds number and Mach number and combined with turbulence and poor flow in many tunnels it becomes very difficult and time consuming to obtain accurate and meaningful data.

The Magnus results to date on the conical and the new boattails are as follows.

(1) The Magnus force on a cylindrical tail and a conical boattail is approximately the same at supersonic speeds, but differs considerably at transonic speeds. The conical boattail has much higher Magnus forces at transonic speeds than the cylindrical tail (Figure 14 and reference 3).

(2) At transonic speeds the Magnus force center of pressure on the 5 caliber cylindrical tail tested is located 55% of the length from the nose while at supersonic speeds the Magnus center of pressure is 70% of the length from the nose. The change in center of pressure location will change the Magnus moment sign of the standard projectile since its center of gravity is usually located near the 60% station. The resulting negative Magnus moment at transonic speeds may cause dynamic precessional instability of the projectile (Figure 15).

(3) The increased Magnus forces on the conical boattail at transonic speeds hold the Magnus center of pressure rearward; however, large positive Magnus moments at transonic speeds can be created by the large Magnus force thereby causing a dynamic nutational instability.

(4) To date the Magnus tests and analysis of data on the new boattail shapes have not been completed but data which is available indicates Magnus data comparable to that of the cylindrical and conical boattails at supersonic speeds while at transonic speeds values close to zero have been obtained (Figures 14 and 15).

(5) The few Magnus tests run on the canted configurations indicate that the canted configurations have higher Magnus forces and moments than the comparable straight configurations. This is most likely true for the straight fins develop higher fin lift which creates higher roll damping and also higher positive fin Magnus forces. This will reduce the overall Magnus force for it cancels more of the body Magnus force (Figure 16).

Aerodynamic damping measurements have been limited to range data and so far indicate that the aerodynamic damping is independent of the configuration (Figure 17). Roll damping measurements have also been restricted to range data and show that the straight boattails have high roll damping. At transonic speeds the roll damping for the square boattail coefficient is -.05 to -.06, the triangular boattail value is -.10 to -.11, and the conical boattail value is -.015. Canting the improved boattails will permit controlling the roll damping.

3. *G. I. T. Nielsen and A. S. Platou, "Effect of Boattail Configuration on the Magnus Characteristics of a Projectile Shape at Subsonic and Transonic Mach Numbers," to be published as a Ballistic Research Laboratories Memorandum Report.*

VI. THE PROJECTILE NOSE

The Army-Navy Spinner Rocket nose, which has been used for these boattail tests, has a high drag and is unsuitable for long range or low drag projectiles. Long, slender noses (Figure 18) have lower drag values, but have the disadvantage of shortening the projectile wheel base. This causes large balloting in the gun barrel, which in turn can be related to excessive barrel wear and large initial angles of attack. Bore riders fastened to the projectile nose alleviate the balloting, but increases the projectile drag and nose lift (reference 4), thereby partially defeating the purpose of the long nose. Also, a long, slender nose projectile has a low payload volume and rearward center of gravity both of which can be detrimental to top performance of a projectile.

A nose formed similar to the triangular boattail, but extended to zero crossectional area (Figure 19) may offer a good combination of all of these requirements. For instance, a 7° cutting plane angle makes the nose 4.07 calibers long and is comparable to the SRC projectile nose (Figure 18 and reference 4). The nose contributes approximately 2 calibers to the wheel base and if used with a 2 caliber triangular or cruciform wedge boattail the wheel base is 4 calibers long for a 6 caliber long projectile. The crossectional area plot (Figure 20) of the SRC and triangular noses show larger volume and more forward center of gravity for the triangular nose. Figure 20 also shows a more uniform area transition to a cylindrical body which may lower the viscous drag at this point. The aerodynamic performance of the triangular nose is yet unknown, but there are plans for testing it in the near future. To decrease the expected high roll damping of the straight triangular nose the configuration to be tested will be spiraled at the gun twist angle (Figure 21) and this may strongly affect the Magnus characteristics as indicated by references 5 and 6. Also, since sharp pointed noses are impractical for most military purposes the nose has been blunted as seen in Figure 21.

---

4. *K. Opalka, "Wind-Tunnel Test of a Spinning, Low-Drag Projectile With Canted Bore Riders at Mach Numbers from 1.75 to 2.5," Ballistic Research Laboratories Memorandum Report No. 2349, Jan 74. (AD #774804)*

5. *M. A. Sylvester and W. F. Braun, "The Influence of Helical Serrations and Bullet Engraving on the Aerodynamic and Stability Properties of a Body of Revolution With Spin," Ballistic Research Laboratories Report No. 1514, November 1970, AD 719235.*

6. *M. A. Sylvester, "Wind Tunnel Tests of Square Base and Boattail Army-Navy Spinner Projectiles With Smooth Surface and 20mm Equivalent Engraving," to be published as a Ballistic Research Laboratories Report.*

VII. CONCLUSIONS

The aerodynamic performance of these boattails appears to be superior to that of the conical boattail. Further wind tunnel and range tests are still required to completely determine their aerodynamic performance.

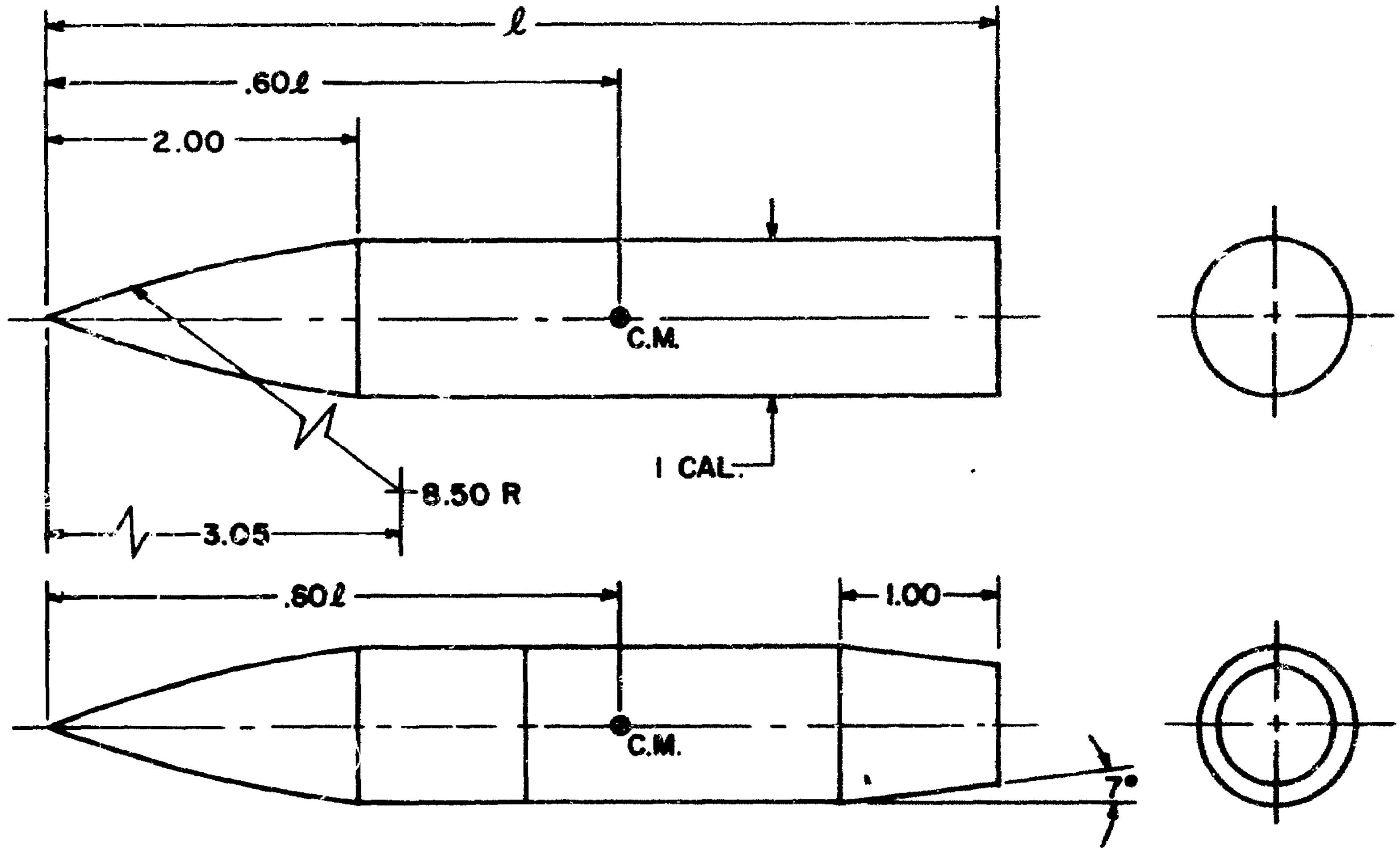

Figure 1. The Cylindrical and Conical Boattail

ALL DIM. IN CALIBERS
ℓ = 4,5,6,7

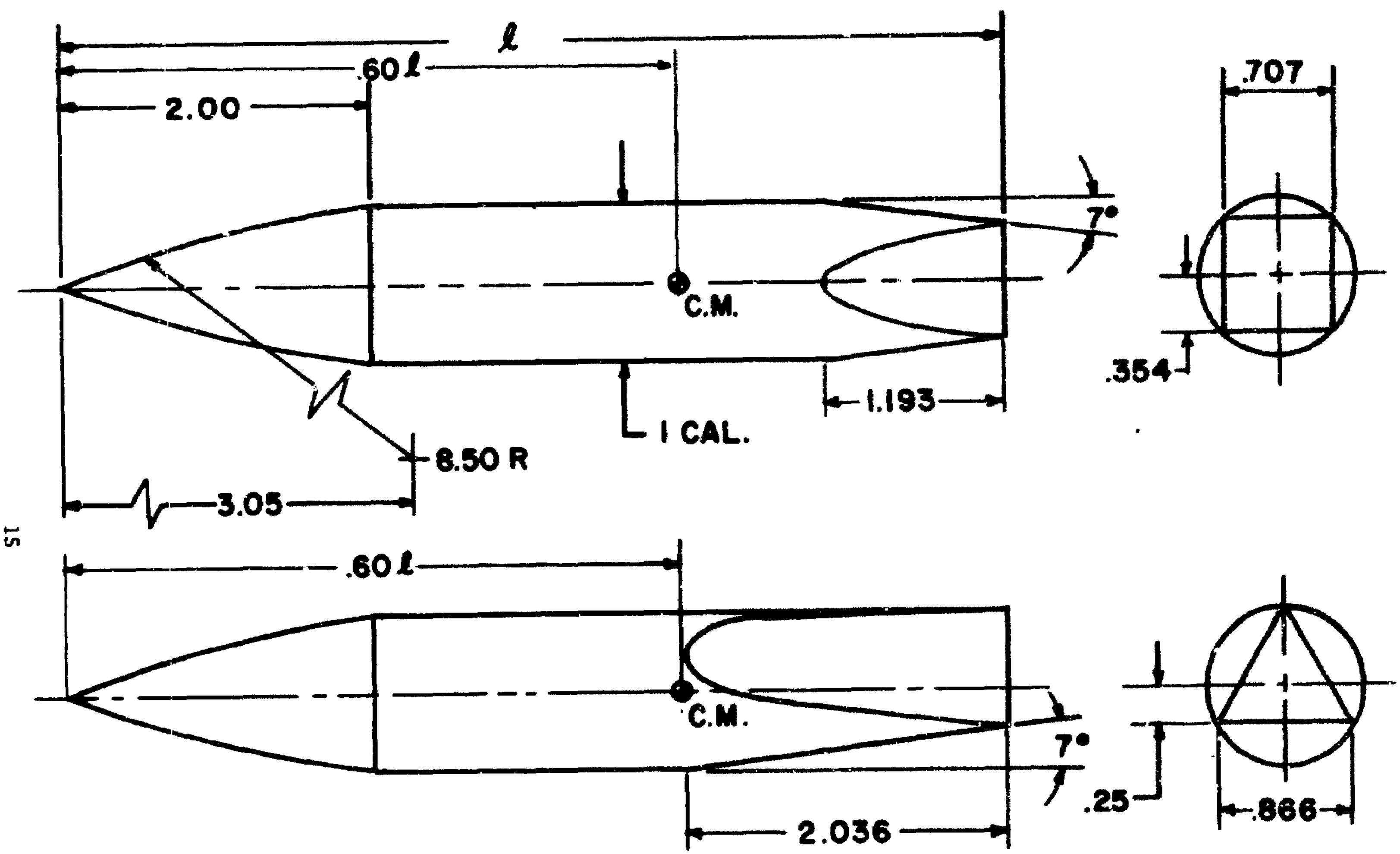

Figure 2. The Square and Triangular Boattail

ALL DIM. IN CALIBERS
$\ell = 5, 6, 7$

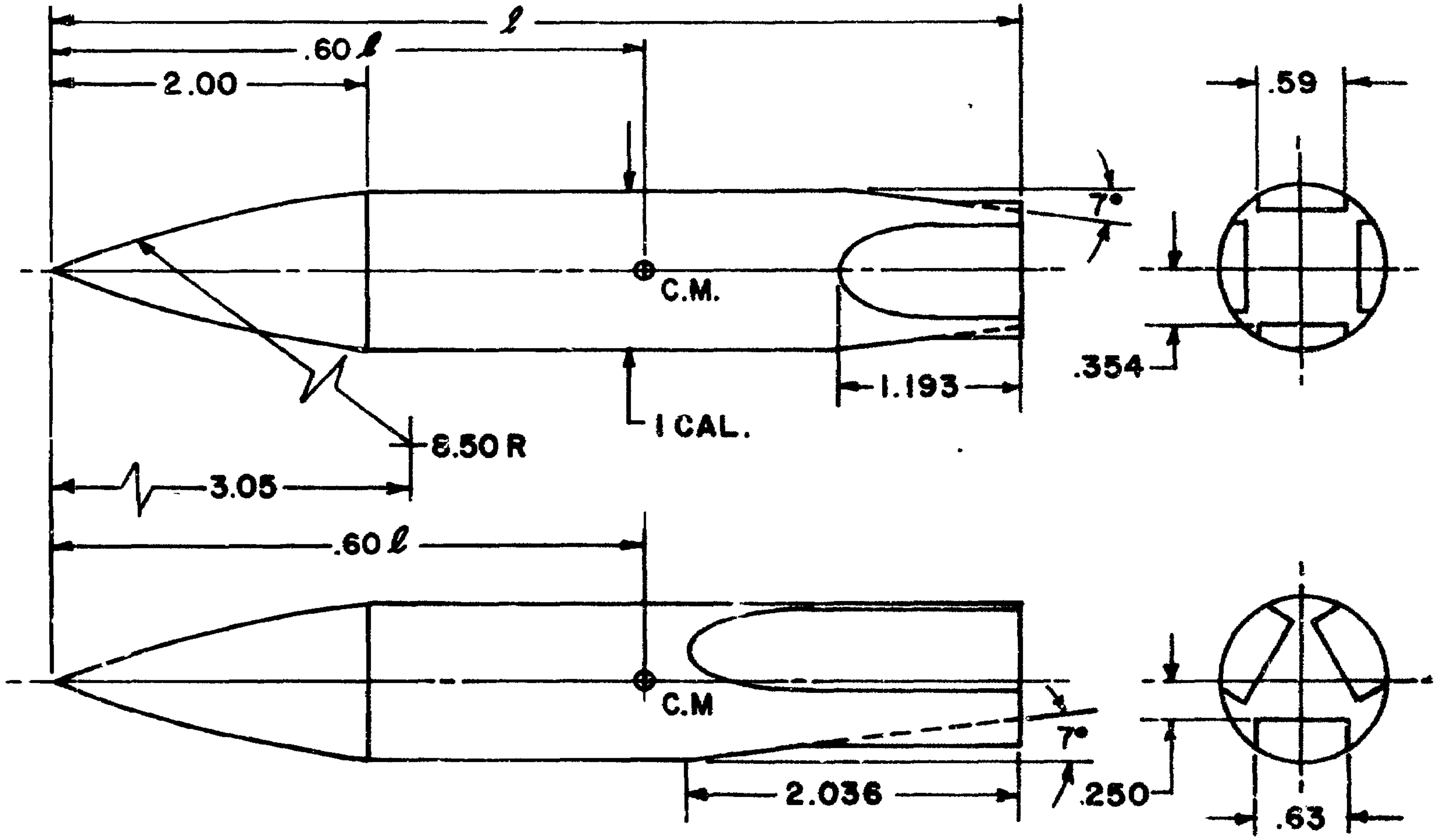

Figure 3. The Added Lifting Surfaces

ALL DIM. IN CALIBERS
ℓ = 4,5,6,7

Figure 4. A Canted Boattail

Figure 5. The Cruciform Wedge Boattail Extended to Zero Base Area

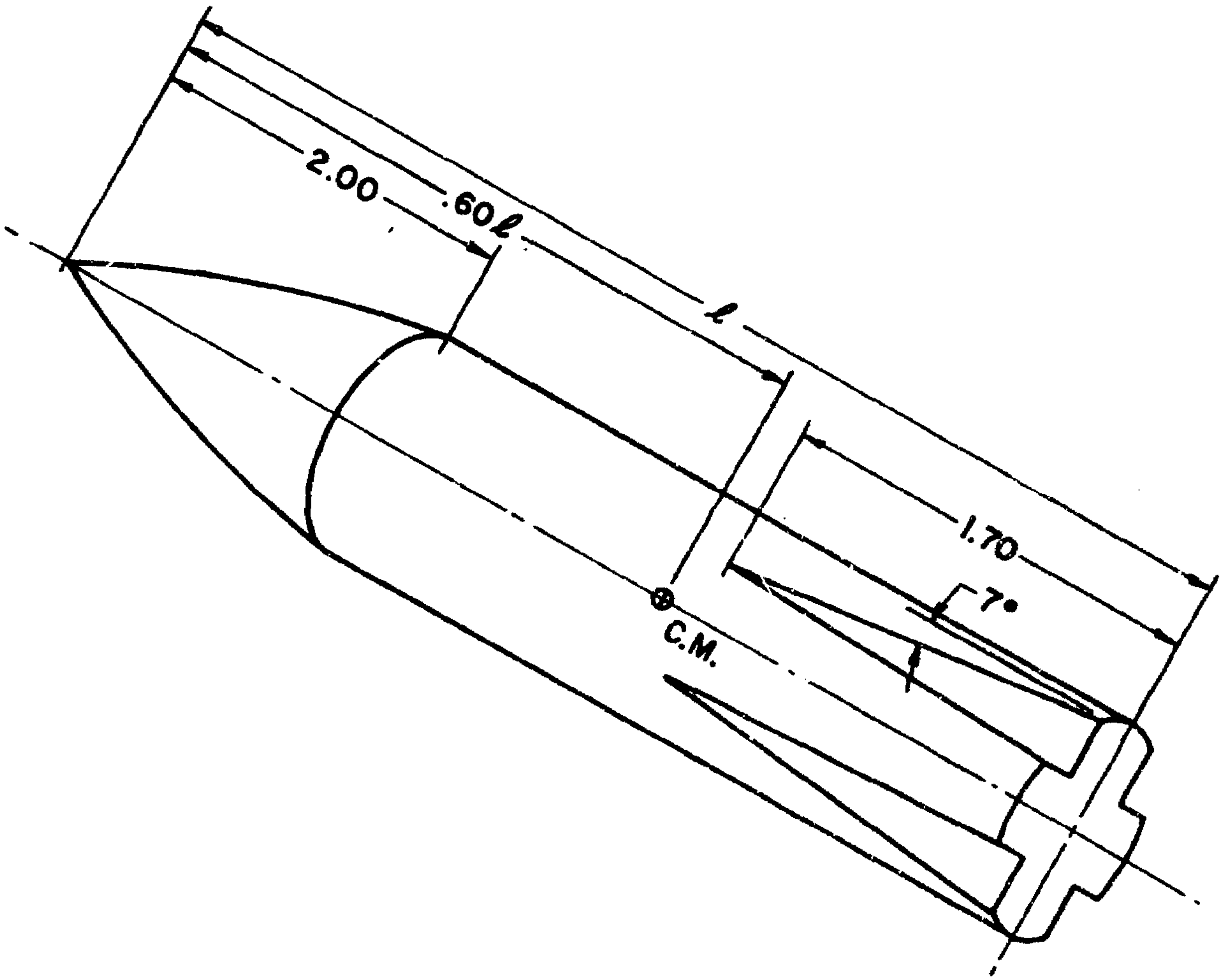

Figure 6. The Cruciform Wedge Boattail Configuration Used for the Wind Tunnel Model

ALL DIM. IN CALIBERS
ℓ = 5,6 OR 7

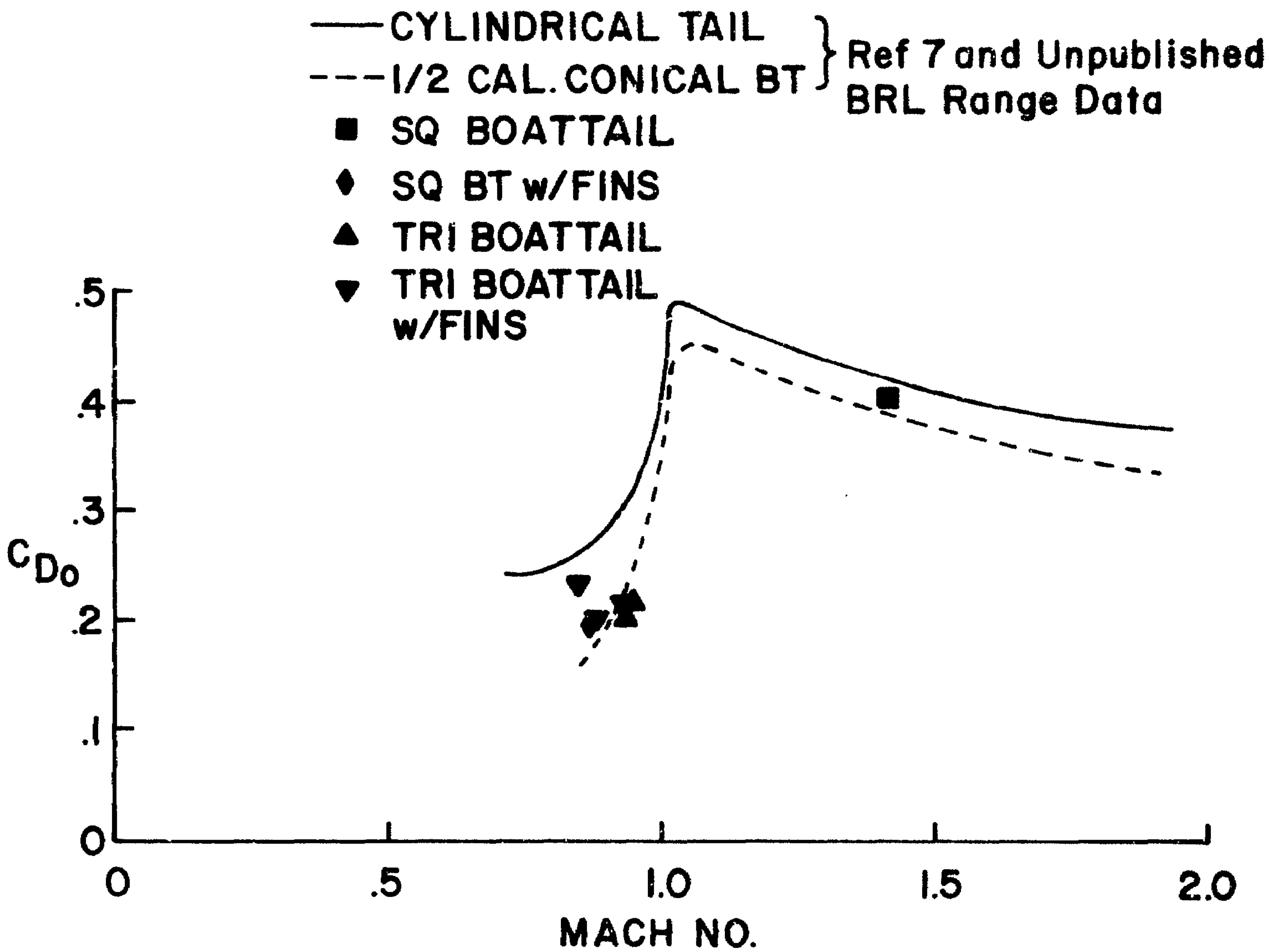

Figure 7. Drag of the 5 Caliber Army-Navy Spinner Rocket with Various Boattails Obtained in the BRL Aerodynamics Range

---

[illegible] C. H. Murphy and L. E. Schmidt, "The Effect of Length on the Aerodynamic Characteristics of Bodies of Revolution in Supersonic Flight," Ballistic Research Laboratories Report No. [illegible], August 1953. AD 23469.

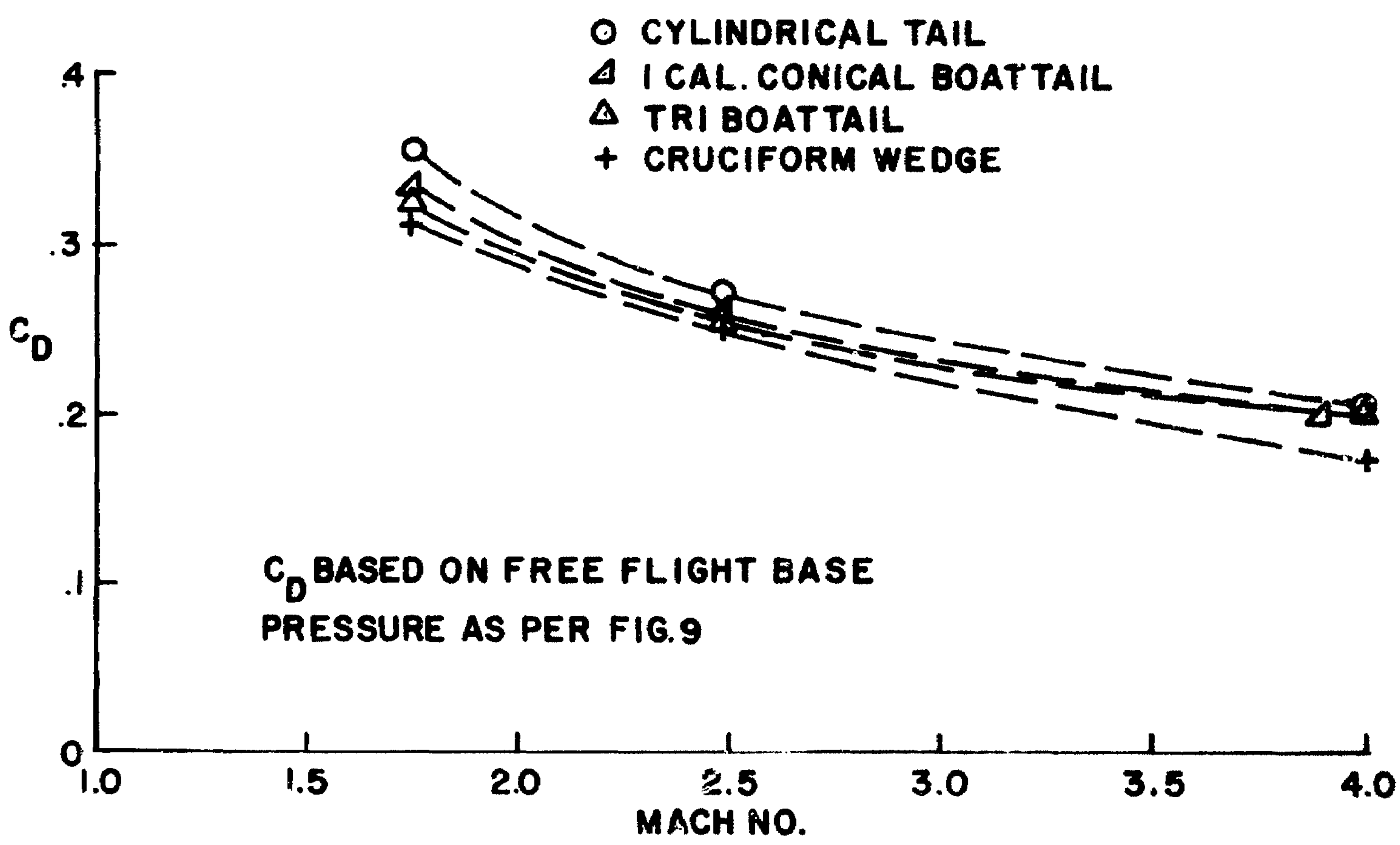

Figure 8. Drag of the 5 Caliber Army-Navy Spinner Rocket with Various Boattails Obtained in the BRL Supersonic Wind Tunnel No. 1

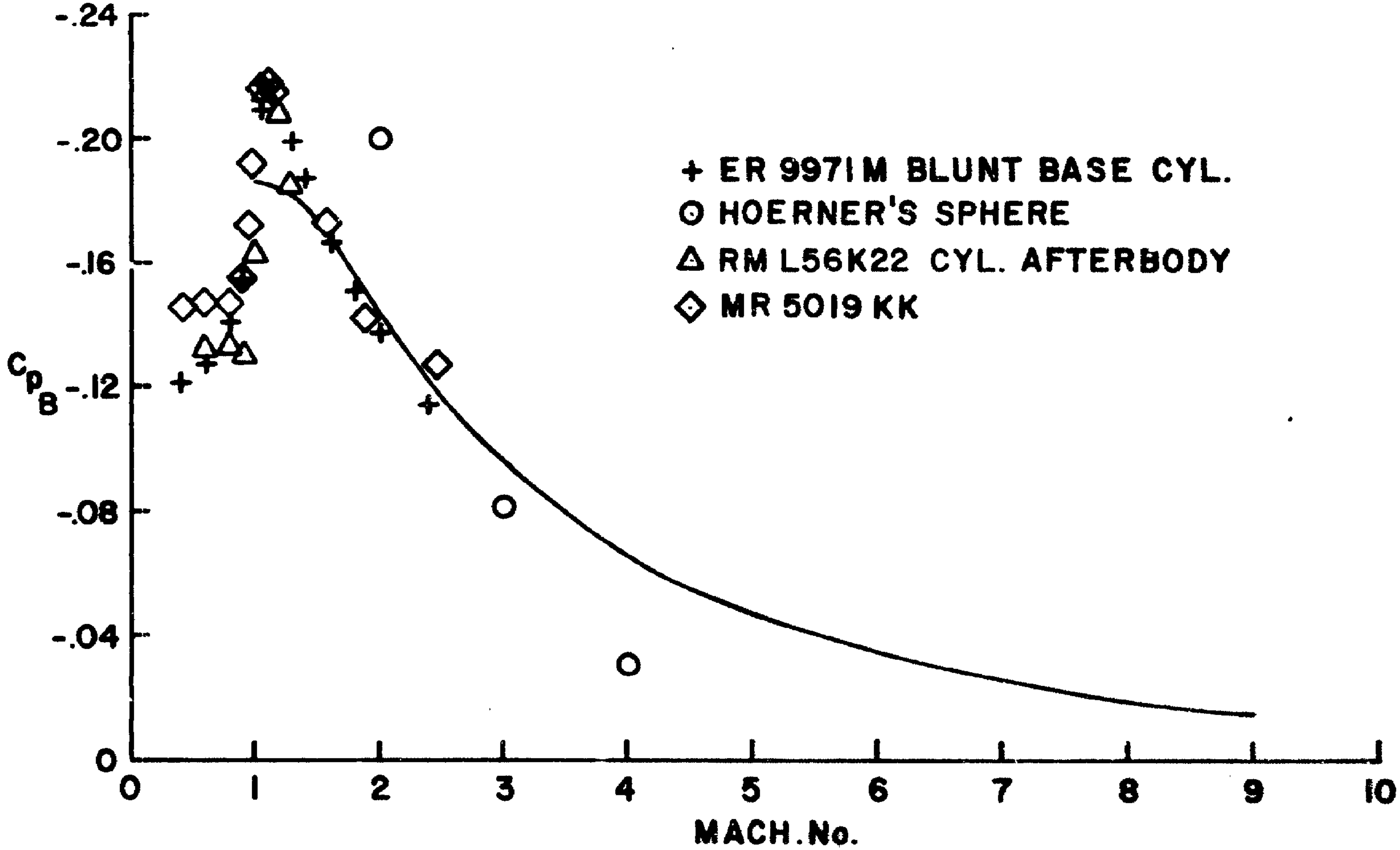

Figure 9. Free Flight Base Pressure Data from Reference 8

8. *E. S. Love, "Base Pressure at Supersonic Speeds on Two-Dimensional Airfoils and on Bodies of Revolution With and Without Fins Having Turbulent Boundary Layers," National Advisory Committee for Aeronautics TN 3819, January 1957.*

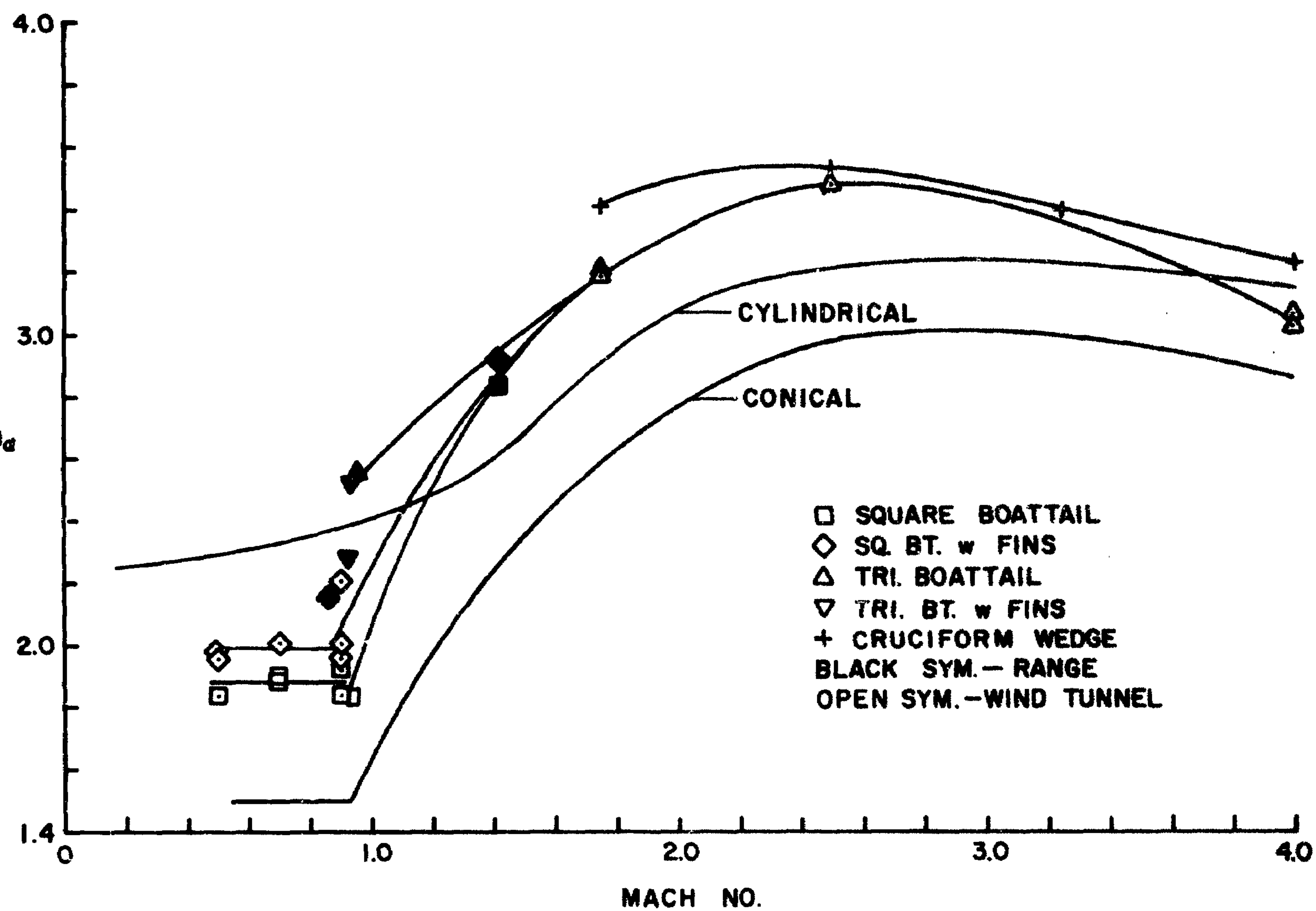

Figure 10. The Normal Force on the Army-Navy Spinner Rocket with Various Boattails

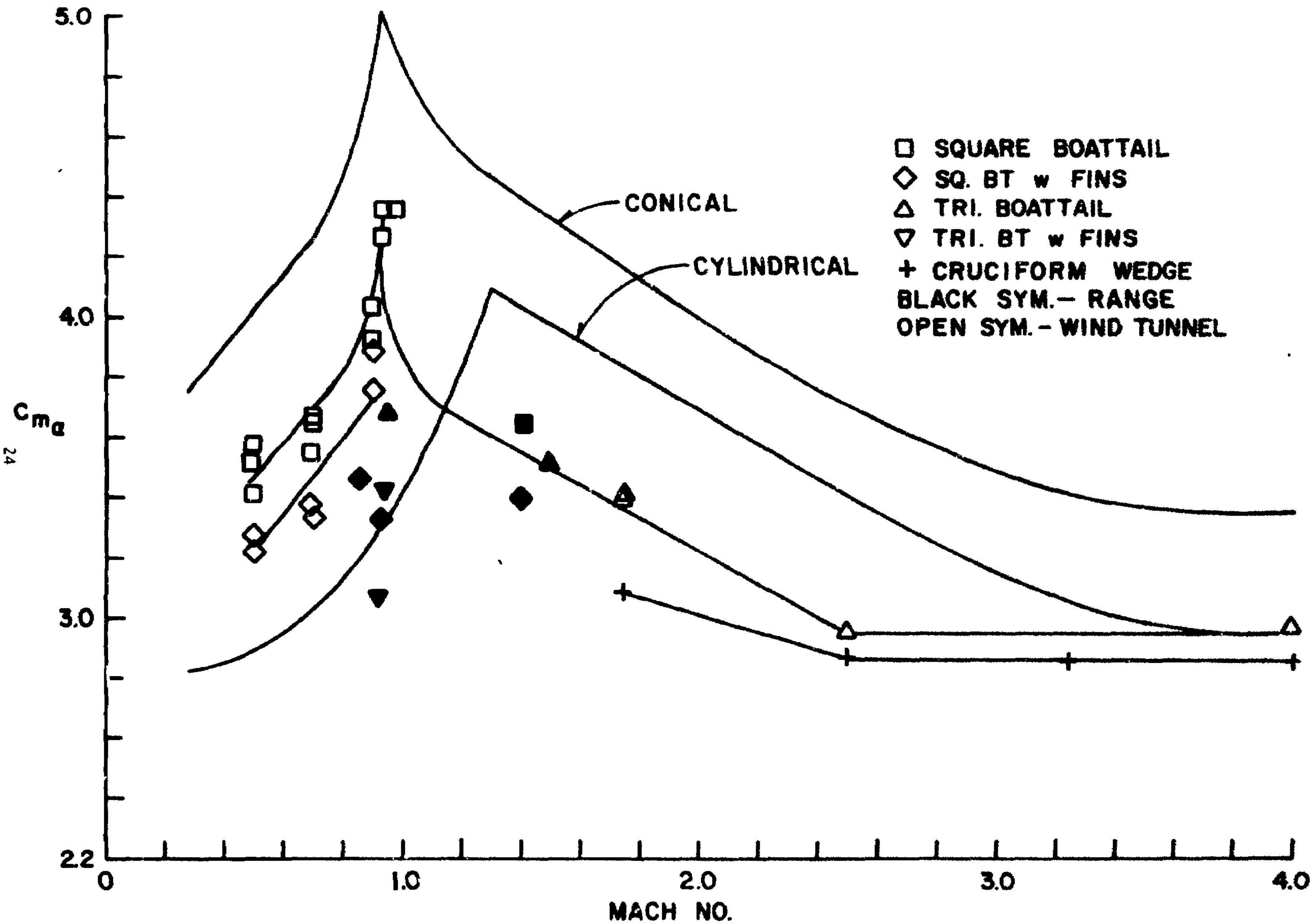

Figure 11. The Pitching Moment on the Army-Navy Spinner Rocket with Various Boattails

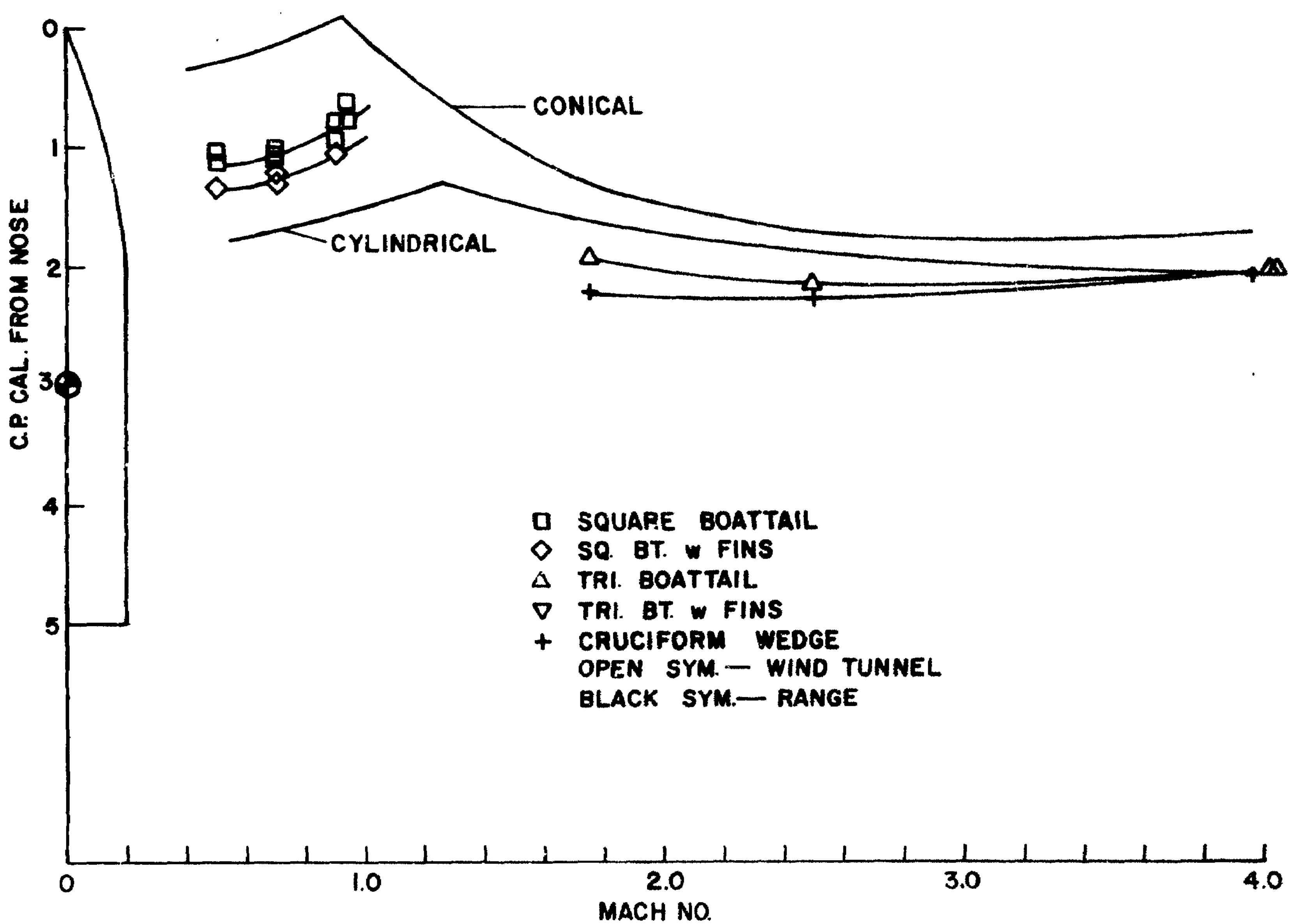

Figure 12. The Center of Pressure on the Army-Navy Spinner Rocket with Various Boattails

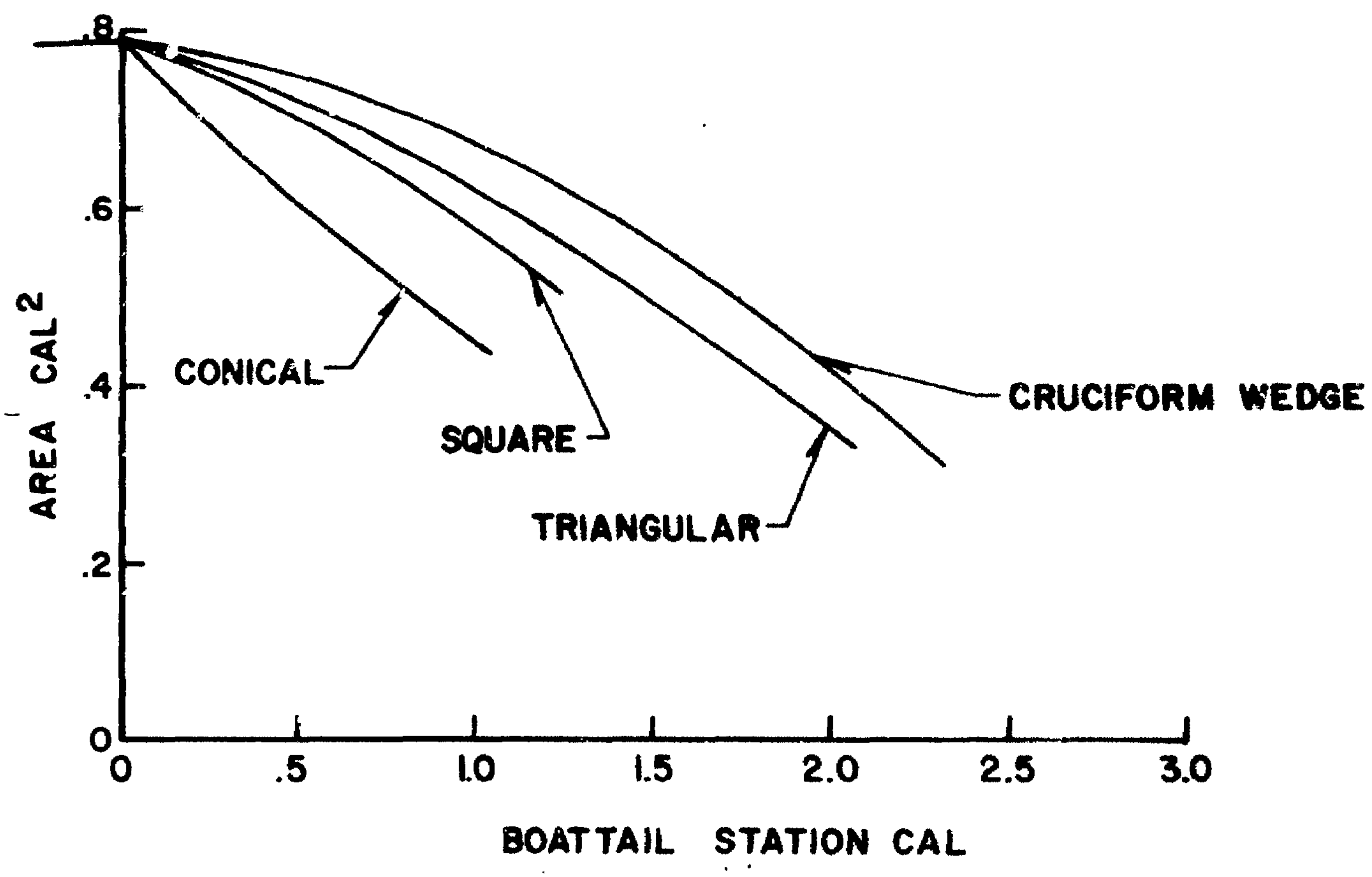

Figure 13. Crossectional Areas of 7° Boattails

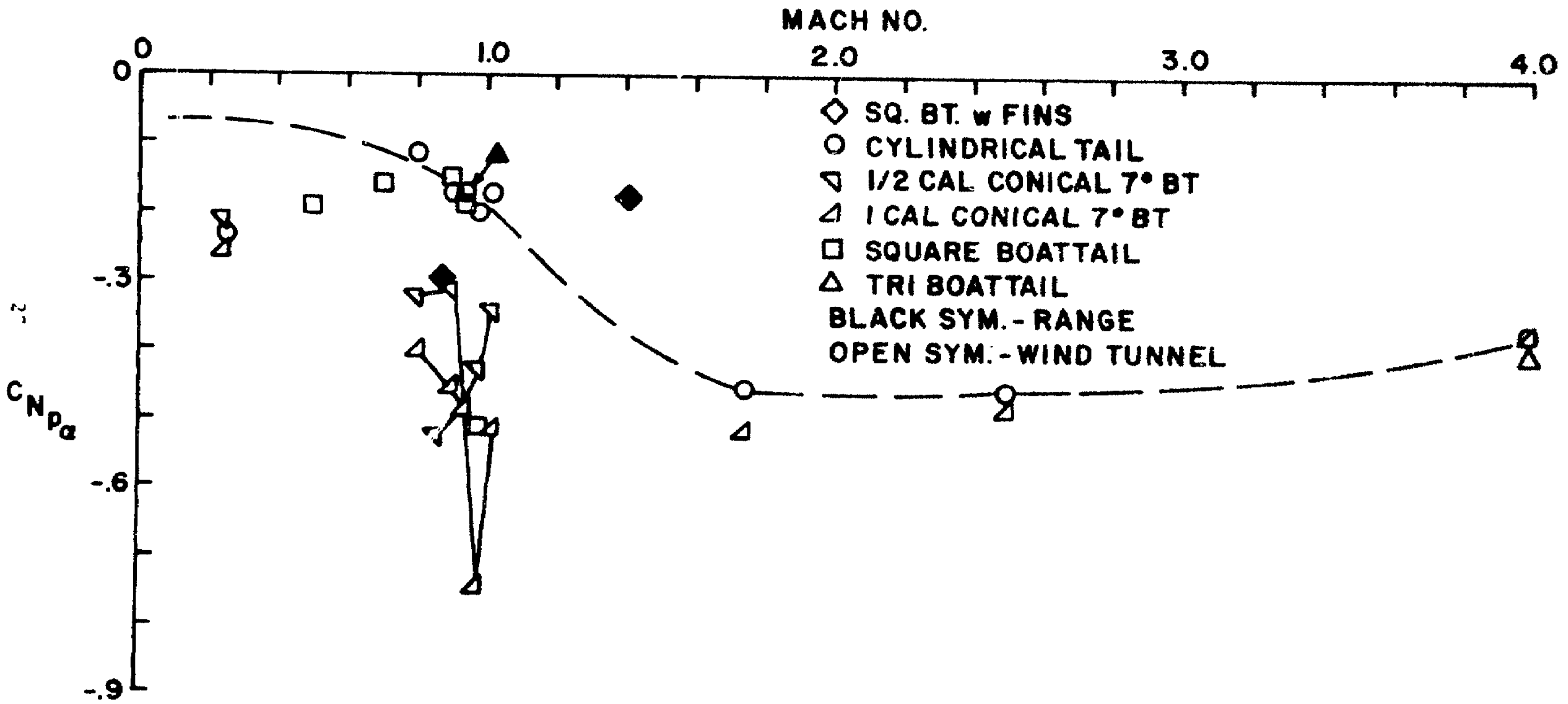

Figure 14. The Magnus Force on the Army-Navy Spinner Rocket with Various Boattails

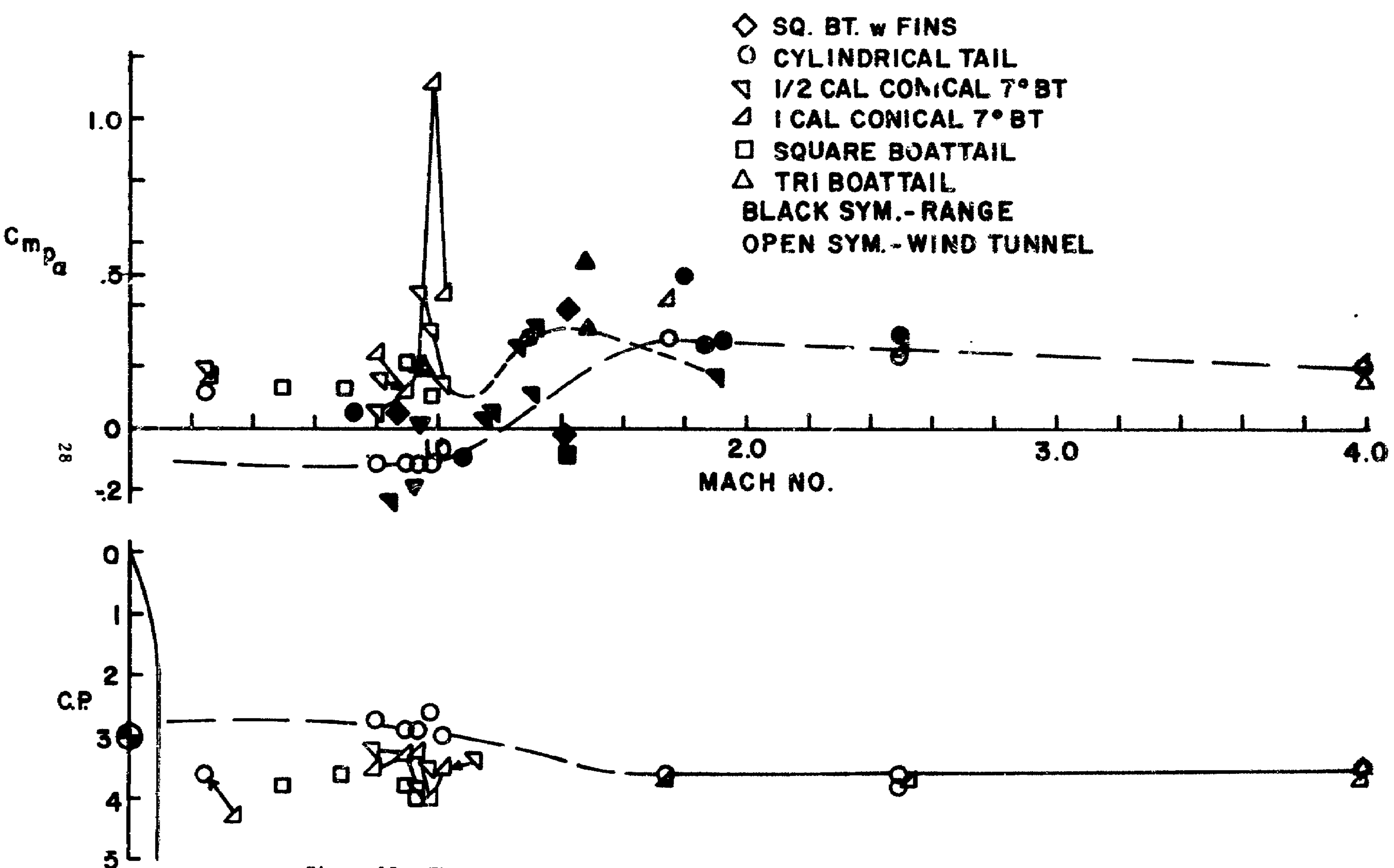

Figure 15. The Magnus Moment and Center of Pressure on the Army-Navy Spinner Rocket with Various Boattails

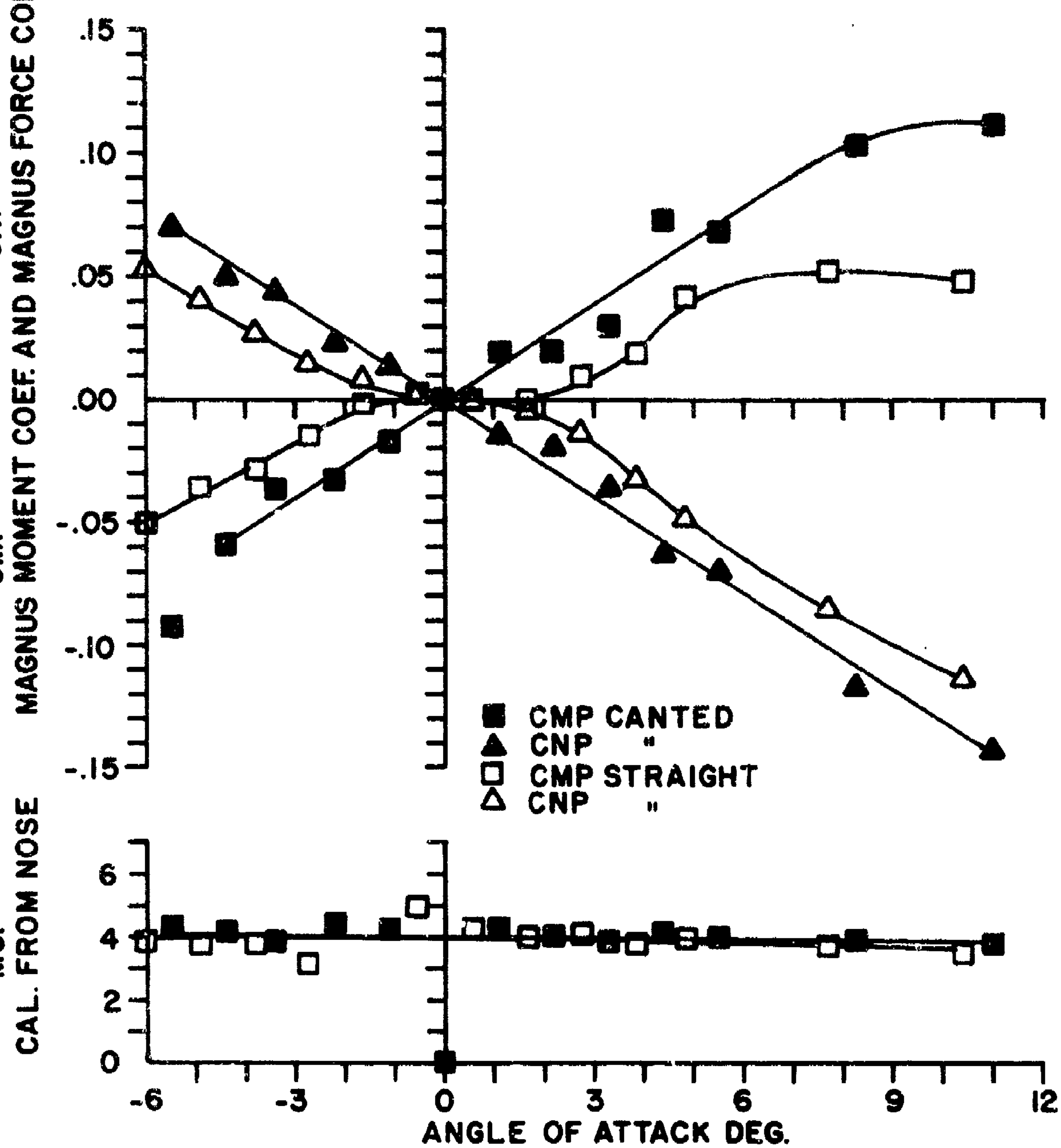

Figure 16. The Magnus Force and Moment Comparison of the Straight and Canted Square Boattails, M = .94, Pd/V = .36

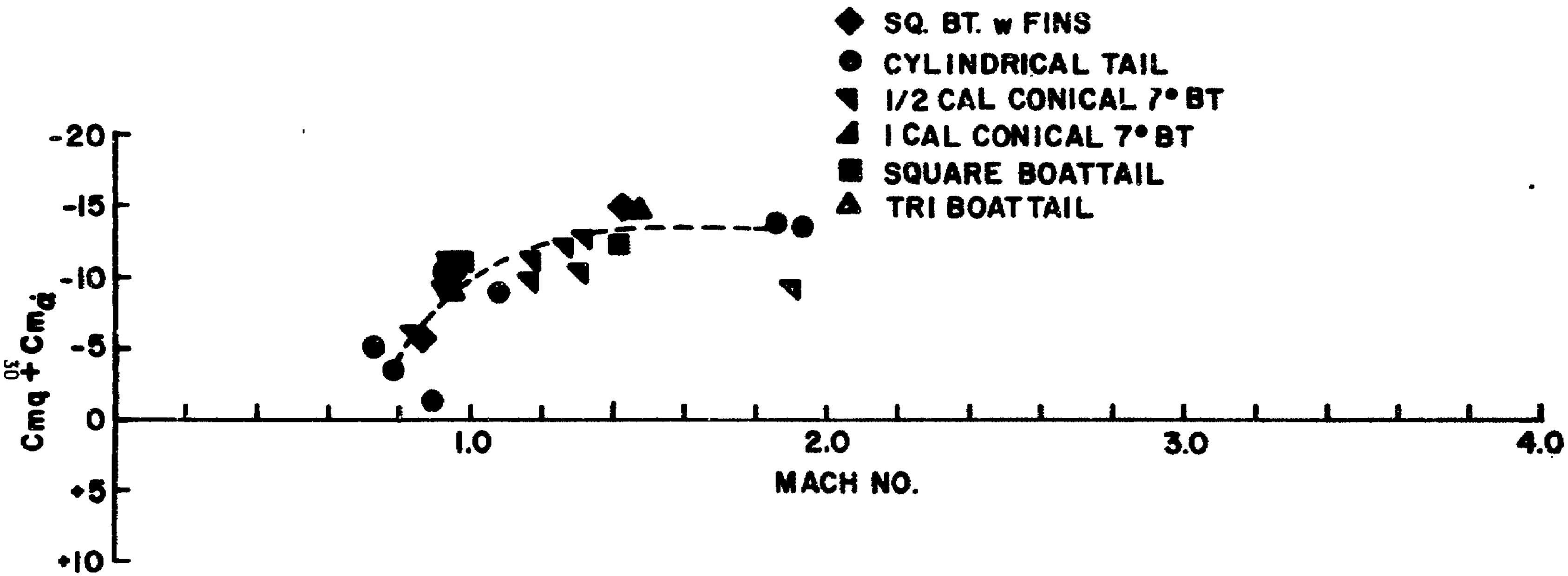

Figure 17. The Damping in Pitch of the Army-Navy Spinner Rocket with Various Boattails

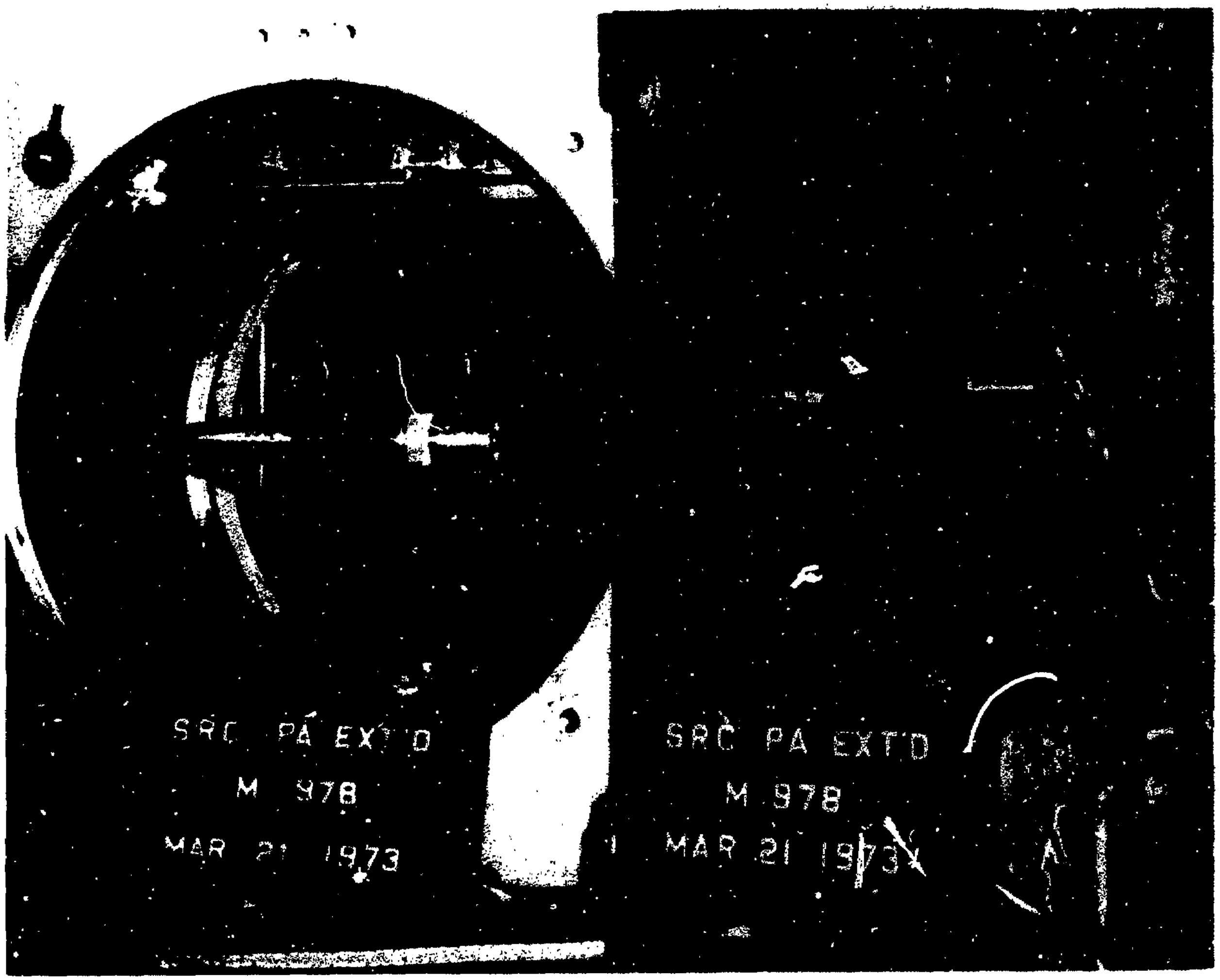

Figure 18. The SRC Projectile With and Without Bore Riders

Figure 19. The Straight Triangular Nose

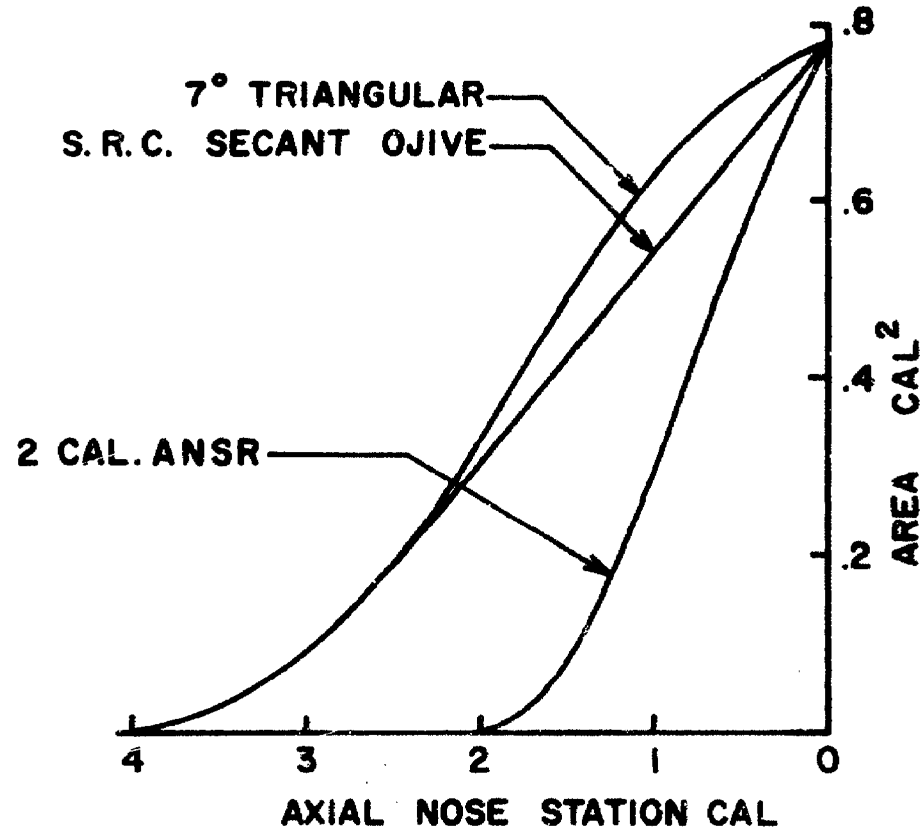

Figure 20. The Crossectional Area Distribution of the SRC and Triangular Noses

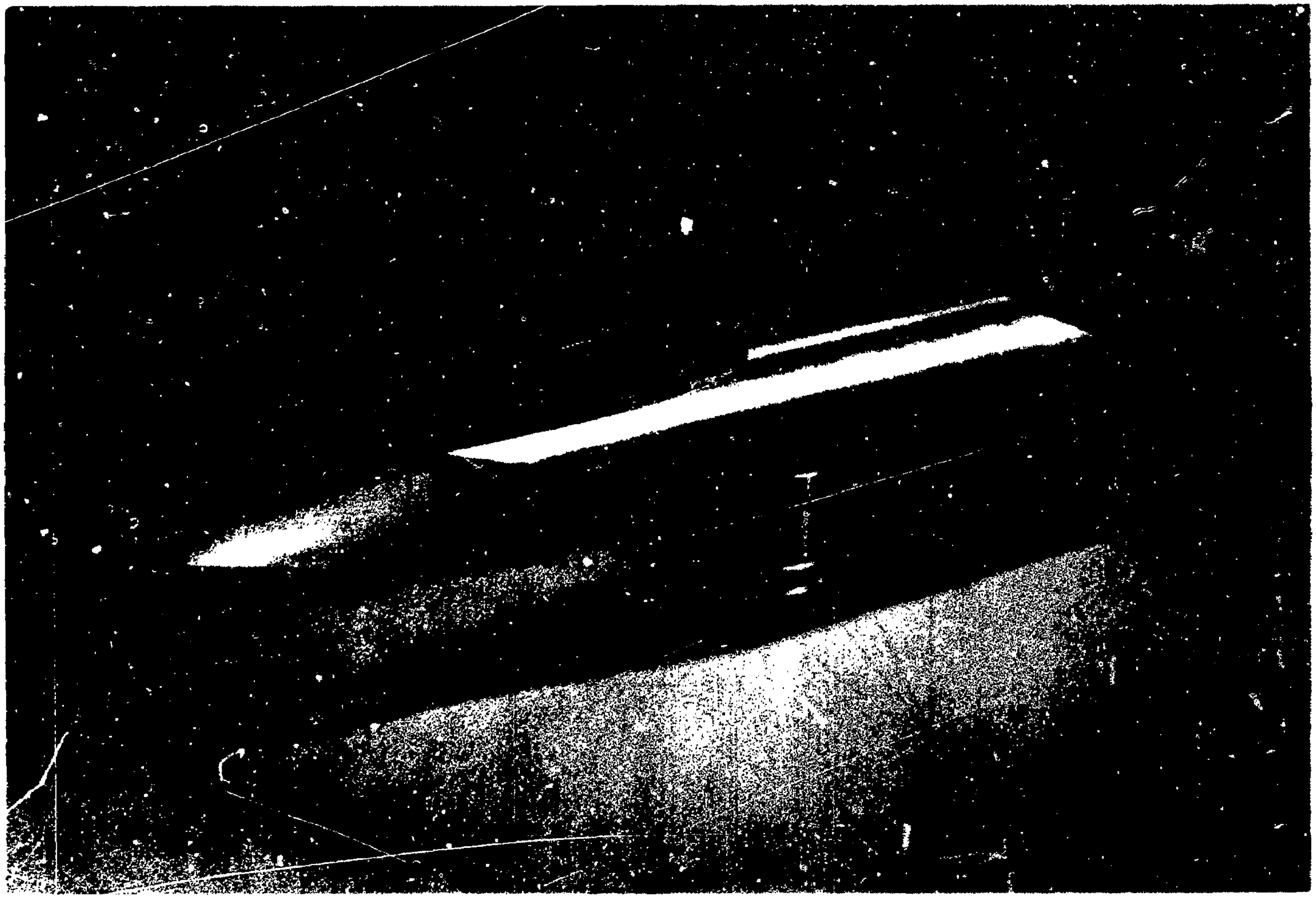

Figure 21. The Canted Triangular Nose with a Canted Triangular Boattail

REFERENCES

1. A. S. Platou, "Magnus Characteristics of Finned and Nonfinned Projectiles," *AIAA Journal*, Vol. 3, No. 1, January 1965, pp. 83-90.

2. A. S. Platou, R. Colburn and J. S. Pedgonay, "The Design and Dynamic Balancing of Spinning Models and a Testing Technique for Obtaining Magnus Data in Wind Tunnels," Ballistic Research Laboratories Report No. 2019, October 1969, AD 699803.

3. G. I. T. Nielsen and A. S. Platou, "Effect of Boattail Configuration on the Magnus Characteristics of a Projectile Shape at Subsonic and Transonic Mach Numbers," to be published as a Ballistic Research Laboratories Memorandum Report.

4. K. Opalka, "Wind-Tunnel Test of a Spinning, Low-Drag Projectile With Canted Bore Riders at Mach Numbers from 1.75 to 2.5," Ballistic Research Laboratories Memorandum Report No. 2349, January 1974, AD 774804.

5. M. A. Sylvester and W. F. Braun, "The Influence of Helical Serrations and Bullet Engraving on the Aerodynamic and Stability Properties of a Body of Revolution With Spin," Ballistic Research Laboratories Report No. 1514, November 1970, AD 719235.

6. M. A. Sylvester, "Wind Tunnel Tests of Square Base and Boattail Army-Navy Spinner Projectiles With Smooth Surface and 20mm Equivalent Engraving," to be published as a Ballistic Research Laboratories Report.

7. C. H. Murphy and L. E. Schmidt, "The Effect of Length on the Aerodynamic Characteristics of Bodies of Revolution in Supersonic Flight," Ballistic Research Laboratories Report No. 876, August 1953, AD 23468.

8. E. S. Love, "Base Pressure at Supersonic Speeds on Two-Dimensional Airfoils and on Bodies of Revolution With and Without Fins Having Turbulent Boundary Layers," National Advisory Committee for Aeronautics TN 3819, January 1957.

LIST OF SYMBOLS

C_D	$\frac{\text{Drag}}{\frac{1}{2}\rho V^2 S}$	positive direction is aft
C_m	$\frac{\text{Pitching Moment}}{\frac{1}{2}\rho V^2 S d}$	Moment center is .6 ℓ calibers from nose. Positive moment is due to positive normal force ahead of the moment center.
C_{m_α}	$\frac{d C_m}{d \alpha}$ at $\alpha = 0°$	
C_{m_p}	$\frac{\text{Magnus Moment}}{\frac{1}{2}\rho V^2 S d \frac{pd}{V}}$	Moment center is .6 ℓ calibers from nose. Positive moment is due to positive Magnus force ahead of moment center.
$C_{m_{p_\alpha}}$	$\frac{d C_{m_p}}{d \alpha}$ at $\alpha = 0°$	
$C_{m_q} + C_{m_{\dot{\alpha}}}$	$\frac{\text{Damping Moment}}{\frac{1}{2}\rho V^2 S d \frac{q_t d}{V}}$	
C_N	$\frac{\text{Normal Force}}{\frac{1}{2}\rho V^2 S}$	positive direction is up
C_{N_α}	$\frac{d C_N}{d \alpha}$ at $\alpha = 0°$	
C_{N_p}	$\frac{\text{Magnus Force}}{\frac{1}{2}\rho V^2 S \frac{pd}{V}}$	positive direction is to right looking upstream.
$C_{N_{p_\alpha}}$	$\frac{d C_{N_p}}{d \alpha}$ at $\alpha = 0°$	
C_{p_B}	$\frac{P_B - P_\infty}{\frac{1}{2}\rho V^2}$	base pressure coefficient
d	main body diameter	

LIST OF SYMBOLS (continued)

M_{CP}	Magnus force center of pressure from moment center
N_{CP}	normal force center of pressure from moment center
p	body axial spin rate (positive is clockwise looking upstream)
p_B	base pressure
p_∞	free stream pressure
q_t	complex transverse angular velocity
S	body area $= \frac{\pi\ d^2}{4}$
V	free stream velocity
α	angle of attack
ρ	free stream air density